MEMORANDUM to the Chief Geologist
through Mr. Bannerman:

TEI-35

Proposed program for and present status
of the Geological Survey's investigation of
domestic resources of radioactive raw materials

by

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INTRODUCTION

This interim report is designed to show the present status of the Geological Survey's information and the parts of a comprehensive program necessary to improve our information about the raw material resources of uranium and thorium. Rarely in geologic work has it been necessary to determine so completely a nation's resources of useful minerals in so brief a span of time. Ordinarily, information on mineral resources is accumulated during a long period of years. However, uranium and thorium were suddenly thrust from a position of subsidiary economic interest into one of great strategic importance. Information concerning their occurrence must, therefore, be obtained as rapidly as reliable methods of investigation will permit. Accordingly the program must be at once comprehensive and carried out over an area more extensive than is usual in the search for and appraisal of most other mineral resources.

ADMINISTRATIVE HISTORY

In May 1944, the U. S. Geological Survey, which had been conducting a reconnaissance exploration within the continental United States for strategic minerals, including the so-called "trace elements," began to emphasize the search for two of these, uranium and thorium.

Four field parties began work in June in areas other than the known deposits of carnotite in Utah and Colorado. Prior to the actual dispatch of the parties to the field, hundreds of samples from mines, mills and smelters throughout the United States were tested for radioactivity. The favorable leads obtained from such tests, and information from geological literature were used as the basis for the field studies. In 1945 the work was extended to include Alaska, after tests of samples from many placer areas had shown the presence of some radioactive minerals.

In October 1944, after a conference with representatives of the Manhattan District, a coordinated Manhattan-U. S. Geological Survey program was established to explore domestic resources. This program operates within the security measures established by the Manhattan District.

The field investigations were initially directed toward occurrences indicated by radioactivity measurements of the many samples available to the survey, and were later expanded along new lines of interest which developed as more data became available. Conducted concurrently with the field investigations were extensive laboratory investigations involving chemical, radioactivity and spectrographic determinations of uranium and thorium content of various materials, all of which required the development of new techniques.

Initially, any material containing more than 0.005 percent uranium or thorium was considered of significant interest. As work progressed, it soon became apparent that material of this grade would run well into billions of tons. Thereafter, only material containing more than 0.01 percent uranium or thorium was considered a potential reserve. It is anticipated that further work will indicate that the minimum percentage figure for potential reserves should once again be raised. As a result of field work supplemented by laboratory and literature research, certain materials such as black shales, phosphatic sediments, placer deposits, manganese deposits, fluorite deposits, tungsten deposits, and late phase differentiates of igneous rocks were found to be the most favorable of all materials examined for the occurrence of uranium and thorium.

PRINCIPAL RESULTS OF THE PROGRAM TO DATE

General Area Covered

The program of evaluating domestic resources of radioactive raw materials has entailed investigations in 31 states and Alaska. It has disclosed much that is new concerning the occurrence, associations, and resources of these materials. Furthermore, the principles and techniques prerequisite to successful search for such materials have been greatly augmented by intensive laboratory research and extensive field investigations of the last few years. Nevertheless, much still remains to be done to increase our knowledge of domestic raw materials and to improve our methods of evaluation.

Methods of Investigation

Field investigations have been partly of a reconnaissance nature to determine whether particular types of rocks or areas merited further investigation and, in the United States, partly of a more detailed nature sufficient to permit an approximate appraisal of reserves of uranium and thorium. Both types of investigation are included in the areas on the maps 1) "Radioactive Raw Materials" and 2) "Areas of Investigations for Radioactive Source Materials in Alaska."

In Alaska the investigations have been of a reconnaissance nature. The results of radioactive scanning of many placer samples, which had been collected at one time or another from producing placers, indicated the more promising areas for examination.

Laboratory investigations successfully evolved or improved new techniques in chemical, radioactive, and spectrographic determinations. As an outgrowth of these investigations, new analytical techniques for the chemical determinations of small quantities of uranium and thorium were established and thoroughly tested. Techniques of radiometric measurement were developed both for making rapid field evaluation of rock types and for serving as a laboratory check on chemical determinations. Spectrographic methods for the determination of small amounts of thorium were also developed.

The laboratory of the Geological Survey has examined for radioactivity more than 4,700 samples collected from mines, mills, smelters and rocks throughout the United States. The information thus obtained has furnished many useful leads in planning field investigations and has made possible the evaluation of the probable merit of many raw materials as sources of uranium, thorium, and the rare earths. In addition many of these samples have been examined spectrographically for about 24 other elements. The general location from which these samples came is shown on map 3) "Mill, Smelter, and Raw Material Sample Localities." The following table shows the proportion of the 1942 production of 14 mineral commodities that have been so examined.

Mine, Mill & Smelter Trace Elements Program
Samples Analyzed Spectrographically - 24 elements*

	Percent of 1942 Production
Copper	40
Lead	90^+
Zinc	90^+
Gold & Silver	50^+
Manganese	90^+
Mercury	95^+
Tin	90^+
Tungsten	90^+
Chromium	95^+
Aluminum	60^+
Iron	A few samples
Pegmatites (lithium, beryllium, feldspar, mica, columbium, tantalum)	20^+
Kyanite, andalusite, sillimanite	30^+
Phosphates	95^+
Coal	A few samples
Miscellaneous igneous, sedimentary, and metamorphic rocks also included in the total number of samples referred to on page 4.	Percentage of coverage undeterminable

* Elements determined spectrographically are As, Be, Bi, Cb, Cd, Co, Cr, Ga, Ge, Hg, In, Mo, Ni, Pb, Pt, Re, Sb, Sn, Sr, Ta, Tl, V, W, Zr

Reserves

The carnotite-bearing vanadium ores of the Colorado Plateau are still the best immediately available reserves of uranium in the United States or Alaska. With the exception of the carnotite ores of the Colorado Plateau, and possibly some of the monazite placers, all the materials investigated are distinctly submarginal in comparison with deposits of uranium ores such as Great Bear Lake, Canada, and Chinkalobwe (Katanga), Belgian Congo. Investigations have shown, however, that pebble phosphate in Florida, the Phosphoria formation in the Idaho-Wyoming-Utah-Montana area, phosphatic nodules in black shale in Oklahoma, and the Chattanooga black shale in Tennessee contain large total quantities of uranium in dilute concentrations.

The location of deposits containing more than 100 tons of metallic uranium together with the percent of uranium by chemical analysis are shown on map 4) "Known Deposits Containing more than 100 Tons of Uranium." The reserves and other pertinent data for deposits containing more than 100 tons of metallic uranium are summarized in the following table.

Reserves in deposits containing more than 100 tons metallic U

Deposit	State	Reserves tons 1/	Percent uranium	Metallic uranium tons
Pebble phosphate	Florida	3.5 billion 2/	0.015	525,000
Phosphoria formation	Idaho Wyoming Utah	600 million	0.011	65,000
	Montana	140 million	0.009	12,500
Chattanooga shale Centerville area	Tennessee	40 million	0.007	2,800
Carnotite	Colo-Utah	1 million	0.14	1,400
Black shale of Woodford chert	Oklahoma	10 million	0.008	800
Temple Mtn., asphaltic zone in Shinarump cong.	Utah	4 million	0.01	400
Nodules in black shale over Checkerboard ls., Tulsa area	Oklahoma	1 million 3/	0.02	200
White Signal dist.	New Mexico	250,000	0.1	250
Placer deposits of central Idaho	Idaho	500,000	0.02 4/	100
Hillside mine	Arizona	500,000	0.02	100

1/ Reserves are stated in terms of inferred tonnage and represent orders of magnitude.
2/ Of this amount 2 billion tons are measured ore.
3/ About 50 million tons of shale required to supply 1 million tons of nodules.
4/ Content of uranium in inferred 500,000 tons of concentrates from 130 million yards^3 of placer gravel. Some heavy mineral concentrates may contain 0.2 percent of thorium, chiefly in monazite.

In addition to the deposits listed above, 12 small bodies, which contain less than 100 tons of uranium each have been found and briefly examined. The aggregate tonnage of uranium in these is about 60 tons.

Mill techniques for recovery of uranium now being developed may alter slightly the ranking indicated above.

So far the work in Alaska has not revealed any deposits comparable in grade and magnitude with the deposits tabulated above. Only a few of the more promising placer areas in Alaska have been examined and the results are significant chiefly as guides to possible bedrock sources of radioactive materials. Investigations of two placer areas in the Seward Peninsula led to the discovery of several small bedrock deposits that carry distinct concentrations of radioactive minerals. The association of these lode deposits with certain intrusive igneous rocks, and the presence of radioactive materials in other known placer deposits that have not yet been investigated, furnish two leads for further investigations that may reveal other deposits of radioactive source materials in the territory.

Favorable and Unfavorable Materials

As data on the occurrence of uranium and thorium has been amassed, certain types of rocks and mineral deposits have been shown to be either favorable or unfavorable for the occurrence of uranium and thorium. Classed as favorable materials are:

- Phosphatic sedimentary rocks
- Some black shales
- Placer deposits
- Some manganese deposits
- Some tungsten deposits
- Flourite deposits
- Mineral districts of the Front Range, Colo.
- Late-crystallizing phases of some types of intrusive igneous rocks
- Marine boghead coals

The following rocks have generally been found to be unfavorable for the occurrence of radioactive materials:

Asphaltite	Limestone
Bentonite	Oil shale
Coal	Pegmatites
Graphitic rocks	Fragmental volcanic rocks
Most igneous rocks	Sandstone

Under special conditions, however, some or all of the rocks classed as unfavorable may contain significant concentrations of uranium or thorium and investigations of these are being continued. For example, sandstone is the host rock for the carnotite ores of the Colorado plateaus, and at Temple Mountain an asphaltic bed carries the uranium minerals.

PLANS AND PROPOSALS FOR FUTURE INVESTIGATIONS

Introductory Statement

Despite the progress made in the last two or three years in evaluating domestic reserves of uranium and thorium much still remains to be done. Field examinations have been extensive rather than intensive, and many areas visited in reconnaissance may need to be reexamined as new information becomes available from a continuing program. Investigations proposed herein which would involve geology and many related fields may indicate new source rocks or point to areas that may profitably be examined. The need for accurate and rapid appraisal of domestic raw materials hardly needs to be stressed to those for whose information this report is prepared. To date, however, our approach has of necessity been largely empirical and, for lack of time, it has been impossible to apply well-considered theoretical lines of approach based on comprehensive application of geologic and related techniques to fundamental problems. The cream of the easily discovered or most obvious sources has been skimmed and a more intensive and more fundamental approach is necessary for further efficient progress.

The search for radioactive raw materials is primarily a geologic problem calling for the application of a wide range of geologic techniques and interpretations. In large measure this is true of the search for all mineral deposits but it is especially so in the search for uranium and thorium because: (1) data acquired prior to 1943 pertain only to the more obvious and high-grade deposits of radioactive minerals, and (2) data recently acquired clearly indicate that certain geologic criteria formerly overlooked can be relied upon to delimit areas favorable to the occurrence of radioactive materials. Many of these materials occur in such small particles that sight identification is impossible, and complex geophysical equipment such as Geiger-Mueller counters or chemical analysis are required for their recognition. Once, however, the presence of such materials is established, the problem of outlining the areas favorable for prospecting and development is chiefly that of delimiting the geologic boundaries. The program for evaluation of raw material resources requires the coordination of geophysical, geochemical, and geological techniques.

The program of desirable future work is divided into several parts, of which many are closely related but are arbitrarily separated for convenience in discussion. Most of the proposed investigations will involve field investigations, physical, chemical and mineralogical investigations in the laboratory, and research in and compilation from the literature. Some of the investigations, however, will involve only one of these techniques. Besides the specific projects that are suggested, chemical analyses and radiometric measurements of many samples will be a highly essential part of the program. Much analytic work will be required and this will have to be coordinated carefully with the other projects undertaken.

Reconnaissance Investigation of Raw Material Resources

Reconnaissance investigations must be continued to discover possible new sources of uranium and thorium, to select the materials or areas that are worthy of more detailed investigation, and to complete information on distribution and occurrences of uranium and thorium. Field investigations are guided by leads developed from radioactive measurements of samples collected in the mine, mill, and smelter program and from other sources, from information on probable associations established by the Trace Elements program, and from information in the literature.

New information developed in reconnaissance and more detailed investigations may make it necessary to reexamine some areas already investigated. For example, a particular kind of rock or mineral association may have been passed over in the preliminary phases of the program as being an unlikely source, whereas later investigations elsewhere may indicate a possible mode of occurrence of uranium or thorium that should be looked for widely.

The areas necessary to complete preliminary reconnaissance coverage of the continental United States are shown on map 1, and of Alaska on map 2. No distinction is made on the maps between areas to be examined in reconnaissance and those to be examined in more detail. Preliminary reconnaissance is incomplete in the following areas:

1. Parts of Texas and New Mexico
2. New England, and northeastern New York
3. Most of Oregon and Washington, and parts of Montana and Idaho
4. Parts of Wisconsin, Minnesota, North and South Dakota
5. Much of Nevada

When these areas are finished large areas in the Central Plains States and in the Gulf and Atlantic Coastal Plains will scarcely have been touched upon. Present information indicates that the geologically young rocks of these areas are unpromising sources of radioactive substances, but subsequent developments may call for their investigation in the future.

Work proposed for Alaska is still largely of a reconnaissance nature and selection of the precise areas in which more detailed appraisal of reserves would be profitable will depend on the results of continuing reconnaissance. The proposed investigations will be governed by the following aims:

1. Verification or disproof of rumored and reported occurrences of radioactive materials.

2. Evaluation of reserves and search for bed-rock deposits in areas indicated by the presence of radioactive minerals in concentrates from placer mining ground.

3. Completion of investigation of Alaskan placer areas.

4. Collecting of concentrates from streams other than those mined for gold, platinum, tin, and tungsten.

5. Determining whether radioactive materials are associated with particular kinds of rock in conjunction with general programs outlined below (p. 12).

Investigations Leading to Estimates of the Grade and Tonnage of Reserves

Investigations leading to the estimate of reserves are of two types: (1) Preliminary investigation to establish inferred reserves, and (2) Development work to block out reserves for possible mining. Only investigations of the first type have been made by the Geological Survey and many of these have been carried out in connection with the preliminary reconnaissance that has been done. Projects of detailed development would be conducted by other agencies, either Governmental or private. Areas in which examinations leading to estimates of reserves have been made or are planned are included on map 1) with those to be examined in reconnaissance. Proposed investigations in sufficient detail to determine inferred reserves or at least orders of magnitude of reserves and content of radioactive substances are as follows:

1. Temple Mountain, Utah.--Examination and sampling of the outcrop and small exploratory workings suggest that about 4,000,000 tons of asphalt-impregnated sandstone containing 0.01 percent of uranium are present in this area. Sufficient drilling is planned to determine continuity of the uranium-bearing zone and permit an estimate of indicated ore.

2. Mineralized districts of Colorado.--The igneous rocks and mineral veins of the Front Range in Colorado have greater than normal radioactivity, and locally the radioactivity of these rocks is much greater. A few small mines in the area have produced uraninite (a mineral rich in uranium), and the ores from some tungsten and fluorite mines contain a maxiumum 0.072 percent of equivalent uranium. The rocks and veins in the more promising areas should be carefully investigated.

3. Mineralized districts of western Montana.--This program is essentially like that in the Colorado Front Range. Particular attention should be extended to veins and zones other than those now being worked for other metals on which information has been more readily obtained.

4. Late-crystallizing phases of intrusive igneous rocks in selected areas.--Reconnaissance investigations have indicated that some late-crystallizing phases of intrusive igneous rocks are greatly above average in radioactivity. Particular areas that should be examined are the Bear Paw, Big Belt, Highwood, and Crazy Mountains in Montana and the Iron Hill area in Colorado. Field investigation of these and other similar areas should be closely interrelated with a more general study of the relation of uranium and thorium to the phases of igneous intrusives other than granitic pegmatites.

5. Detailed reconnaissance in the plateau part of Colorado, Utah, New Mexico, and Arizona.--The principal vanadium and carnotite producing districts of this region have been examined by numerous organizations. Additional investigation is recommended to fill in gaps left from previous examinations and to extend work to areas peripheral to the districts already examined.

6. Rocky Mountain phosphate field.--The phosphatic beds of the Rocky Mountain phosphate field in parts of Idaho, Montana, Utah, and Wyoming constitute a very large low-grade reserve (see table, p. 5) of uranium. Sufficient work is recommended to locate all the better areas of uranium-bearing phosphate rock in areas not yet examined and to complete our data on the phosphate field.

7. Investigations in other areas.--Recommendations for other investigations in sufficient detail to evaluate reserves would depend on the following:

a. Results of reconnaissance and more detailed investigations recommended here.

b. Results of experiments now in progress on the relative amenability of different types of rock to treatment for extraction of uranium.

c. Progress in the improvement of techniques for locating ores.

d. Results of various proposed research investigations outlined below, which may suggest specific areas or materials for further investigations.

8. Development work to block out reserves for possible mining.--Until investigating agencies are informed of the amount of uranium needed for present and projected uses, and the minimum grade requirements are established, areas for development work cannot be properly selected. Present information would furnish the basis for such a selection. Development and blocking out of ore would then be a function of agencies other than the Geological Survey.

Identification, Determination, and Treatment of Radioactive Substances

Research on the improvement of techniques for radiometric and chemical analyses of samples have been conducted concurrently with a large volume of routine analytical work in connection with investigations of raw material resources. Provision must be made for an even greater volume of routine determinations if the program is expanded. Further research in the improvement of various techniques for determining the presence, amounts, and nature of radioactive substances is essential to reducing the load of routine work involved in a comprehensive program and to evaluating information obtained in the field. The following projects are proposed:

1. Research on improvement of techniques.--

a. Neutron measurement: Application of more rapid methods of determination of uranium, such as neutron measurement, need to be developed to meet the requirements especially of mill processes. This work properly falls within the province of physical laboratories other than those of the Geological Survey.

b. Chemical: Accurate but slow methods of chemical analyses for very small concentrations of uranium have been developed, but more rapid methods are still needed. Progress on determining thorium have not been so rapid, and studies are being continued by the Geological Survey, but these should be supplemented by similar work in other laboratories.

c. Spectrographic: The spectroscope has been developed into a highly useful tool for quantitative determinations of many elements. Its application to determinations of uranium and thorium within the smaller ranges of concentrations of much interest in this program has not been so successful. The time consumed by chemical methods of analysis is a severe handicap at all stages of evaluation of the quantity and usefulness of radioactive raw materials. Because of the large amount of analytical work that will be required by the various investigations proposed here, limits of accuracy of the spectroscope and of methods of improving its sensitivity should be pursued energetically jointly by the Geological Survey and other laboratories especially well qualified for such work.

d. Geiger-Mueller counter: Although Geiger-Mueller counters have been much improved in recent years, further improvement especially of field counters is a continuing need. As the sensitivity and reliability of these counters is improved, field examinations and especially reconnaissance can be conducted more rapidly and efficiently. This work is properly a function of agencies other than the Geological Survey.

e. Extraction of uranium and thorium from source materials: Evaluation of deposits of raw materials depends not only on the amount and concentration of uranium and thorium in them but on their amenability to treatment for recovery of the uranium and thorium. Work of this type clearly does not fall within the province of the Geological Survey, and is currently being conducted by other organizations. Continued investigation of the metallurgical problems connected with various types of materials is a highly necessary part of the program and should be done by qualified Governmental or private agencies.

2. Mineralogic and petrographic studies.--The field investigations of recent years have disclosed hitherto unknown associations of uranium. Thus far, the pressure of other duties and limitations of personnel have prevented adequate study to determine the mineral or minerals that carry the radioactive elements in many materials. This information is important as a guide to further prospecting and as a suggestion of methods to recover uranium from such deposits. Comprehensive mineralogical and petrographic studies using various techniques of micromineralogy should be an essential component of all investigations of radioactive raw materials. Although the actual work employs laboratory techniques, such a program must be well integrated with programs of field investigation, especially those related to fundamental geologic research and milling of ores.

3. Degree of radioactive equilibrium.--The degree to which radioactive equilibrium attains in different source materials and in different geologic environments is important in evaluating the significance of tests of radioactivity by means of a Geiger-Mueller counter. Equilibrium attains only when uranium and the complete suite of its daughter elements are present in certain fixed proportions that depend upon the rate of decay of the various radioactive elements forming the suite. Measurement of radioactivity by physical means indicates the amount of uranium present only when all the daughter elements are present in their normal or equilibrium proportions. Thus if the processes acting on source materials cause selective removal or enrichment of either uranium or some of the products of its radioactive decay, the measurement of radioactivity will not give a correct measure of the amount of uranium present.

Furthermore, the accumulation of sufficient information on the sites in which different deposits are leached or enriched would indicate the probable sources and the directions of circulation of radioactive ground waters. A better knowledge than we now possess of the factors that influence leaching and enrichment may lead to the discovery of deposits that are lower in total radioactivity but richer in uranium.

Much of this investigation should be a laboratory study, but the collection of materials to be studied would be part of a field investigation and the results would be most useful in field evaluation of sources of radioactive materials.

Comprehensive Studies of Specific Areas

Comprehensive geologic studies of some areas of radioactive raw materials are important to knowledge of the occurrence and distribution of uranium or thorium therein and to more effective evaluation and possible utilization of the resources. Such studies are proposed for three areas. Doubtless investigations in other places pointed more directly toward appraisal of reserves or the special studies proposed below (p. 12) will suggest additional area studies.

1. Vanadium-carnotite deposits of southwestern Colorado and southeastern Utah. The carnotite-bearing vanadium deposits of Colorado and Utah have been the largest source of uranium in the United States. Up to 1945 and mostly since 1936, about 900,000 tons of carnotite ore that averaged from 0.20 to 0.25 percent U_3O_8 have

been produced from this region. The individual deposits have a wide but spotty distribution. Many contain less than 1,000 tons of ore, some contain 10,000 tons, and a few containing more than 50,000 tons have been mined.

Most of the known deposits have been discovered at the outcrop, and the ore has been followed underground by mining and located by diamond drilling from the surface ahead of the mining faces. As most of the exposed deposits that have been found are partly or completely mined out, new discoveries will have to be made by the more costly methods of subsurface prospecting. Because of spotty distribution of the deposits, regional geologic mapping is needed so that subsurface prospecting can be guided efficiently and economically. Such regional maps would establish regional trends, variations in the character of the deposits, and conditions of localization of ore, and permit comparative evaluations of the chances of finding ore in different areas. For effective interpretation of the geology, topographic maps are an essential part of the program. These maps can be prepared by the Topographic Branch of the Geologic Survey from aerial photographs. This investigation would be a continuation of work previously started for the evaluation of the vanadium resources; and it should be pressed energetically because of the importance of the region as a currently available source of uranium.

2. The monazite-bearing granites, stream placers, and beach sands of the Carolinas. It now appears that the largest and most extensive monazite deposits in North America are those of North and South Carolina. Here monazite occurs in a belt roughly 200 miles long and 15 miles wide, coextensive with the outcrop of a gneissoid granite which is believed to be the source-rock. A reconnaissance geologic map of this gneissoid granite and the sampling of alluvial concentrates in the streams that drain this belt of outcrop would provide the data for (a) detailed investigation of the more promising areas and (b) reconnaissance examinations to trace the monazite down some of the streams and, if possible, into the monazite-bearing beach sands on the Atlantic coast.

The Carolina monazites are known to vary in composition and some of their physical properties. To afford the most useful information, this field investigation should be accompanied by office and laboratory studies to discover possible relations between differences in composition, radioactivity, specific gravity, and magnetic properties of pure separations of the monazite.

3. Schroeckingerite area of Wyoming.--A small and relatively low-grade deposit of schroeckingerite in Wyoming has been examined in sufficient detail to determine the order of magnitude of the reserves. The deposit, however, raises many unsolved questions about the conditions favorable to deposition of the unusual mineral and the ultimate source of the contained uranium. For these reasons this occurrence merits a thorough study of the mineralogy, chemistry, and geologic setting, in order to assess the likelihood of more extensive deposits in the vicinity.

Broader Problems Related to Specific Types of Occurrences of Radioactive Substances

The investigations included under this heading would be those directed toward better knowledge about the geologic relations of uranium and thorium. This in turn would improve the ability to appraise places or materials in which higher than average concentrations of these elements may occur. Many of the suggested projects are of necessity long-range, but present information on the geology and geochemistry of uranium and thorium is still so incomplete that any of these lines of approach may yield fruitful results. Many phases of the work suggested earlier in this report would be intimately connected with types of investigation proposed here.

1. Concentration of U-Th during crystallization of igneous rock.--Late stage magmatic products in the solidification of some masses of intrusive igneous rock, especially those of silicic and alkalic character, have considerably higher radioactivity than average igneous rock. A varying content of radioactive elements is also found in several accessory minerals which are among the early products of crystallization in some igneous rocks. Further study of both of these stages in the solidification of the intrusive igneous rocks with respect to the concentration of the radioactive elements appears highly desirable on the basis of the reconnaissance work up to this time. Significant deposits of radioactive materials may be found during the course of investigations, and information obtained on the relative stages at which concentration of the radioactive elements occurs would furnish a guide in further search for possible workable deposits of these elements.

2. Conditions of deposition of radioactive materials in modern marine sediments.--Many of the most extensive low-grade deposits of radioactive materials in this country and elsewhere (the Florida phosphates, the Phosphoria formation, the Phosphoria formation, the Chattanooga shale, the black shales that contain the Swedish kolm) are of marine origin. It is significant that numerous oceanographical investigations have shown that U, Th, and several of their daughter elements are differentially segregated by various biologic, physical, and chemical processes that are operative in the sea today. It is reasonable to anticipate that the principles governing the segregation of radioactive materials in sea water, marine organisms, and bottom sediments today may afford valuable clues to a better understanding of the factors that controlled deposition of similar materials in marine sediments of the geologic past. A study of available oceanographic and other data on the occurrence of radioactive materials in modern marine sediments should be undertaken. Such a study may lead to the formulation of at least some generalizations applicable to ancient sediments. Some of these generalizations should, if possible, be tested by experiments in the laboratory and by the collection of bottom sediments at certain critical localities. Some aspects of this project would require cooperation between various organizations conducting terrestrial geologic surveys and those engaged in oceanographic studies.

3. Possibility of higher-grade deposits in black shales, marine oil shales, and boghead coals.--In Sweden an extensive marine shale of Cambrian age, approximately 100 feet thick, has been used as a commercial oil-shale or low-grade coal. In its uranium content, this Swedish shale is similar to parts of the Chattanooga and Phosphoria formations of this country. However, the Swedish shale also carries thin discontinuous lenses of a highly organic rock, known as "kolm," which contains as much as 0.5 percent U. No close analogues of this Swedish kolm have thus far been found in this country. It is proposed by a more intensive study of highly carbonaceous shales, marine oil shales, and cannel or boghead coals to continue the search for (a) possible analogues of the kolm and (b) possible stratigraphic and paleogeographic criteria that would indicate parts of black shale formations, in general, likely to be most favorable for accumulation of uranium. Such a study will require a thorough review of the literature and unpublished data in the files of the Geological Survey to gain an insight into the conditions of deposition most favorable to the accumulation of uranium in these types of rocks. The results of this initial review can then be subjected to an effective and economical plan of field testing.

4. Helium-bearing natural gas.--Alpha particles emitted by radioactive disintegration of U or Th become helium atoms by attracting two electrons. Thus it is reasonable to infer that abnormal accumulations of helium may be an indication of nearby sources of uranium or thorium. But an important question remains, namely, whether the helium is concentrated from disseminated deposits of large extent or from a more localized deposit of high-grade ore. The problem is worthy of attention to determine whether helium-bearing natural gas can be used as a guide to source rocks of U and Th.

5. Radioactive spring and oil-field water.--In many localities mineral springs and well waters are radioactive and some of these waters deposit radioactive materials. The objective in a study of radioactive waters would be to determine whether or not the radioactive materials, presumably radon gas and its daughter elements, are supplied by nearby rocks that contain appreciable quantities of uranium and thorium. Such a study would involve a careful examination of the circulation of ground water.

6. Gamma-ray well logging.--Many companies producing oil and potash have systematically logged gamma-ray activity of the strata penetrated in their wells. The great bulk of this information is in the files of the interested concerns and has not been examined. A determined effort should be made to obtain access to this information, for it may prove to be a most useful guide to possible new source rocks of uranium and thorium.

7. Abnormally steep geothermal gradients as a possible guide to deposits of radioactive minerals.--The energy released during radioactive decay is largely dissipated as heat and it is therefore logical to expect that geothermal gradients will be steeper near large deposits of uranium and thorium than elsewhere. However, clear-cut evidence in support of this expected relationship appears to be lacking. It is proposed to examine this problem of radioactive heating quantitatively, considering the heat released by a given deposit, the thermal conductivity of adjacent rocks, and the available evidence of geothermal gradients. It seems probable that such an examination will point to the need for measuring new geothermal gradients in certain critical areas. If the expected relationship is confirmed, geothermal gradients may become one line of evidence useful for detecting and estimating the extent of buried deposits of radioactive minerals.

Bibliographic Research and Compilation of Information from the Literature

Effective planning and guidance of a research program extending literally over half a continent and involving a largely untouched field requires compilation of information from as many sources as possible. This is particularly true of geological investigations where much of the data cannot be synthesized into rules of general application. Therefore, much of the whole range of geologic and related literature is being examined to determine where, and in what quantity, possible source materials of uranium and thorium may be present, and how easily they may be examined.

The detailed geologic information that may be of use is scattered through numerous scientific and trade periodicals and publications of the government and 48 states. When one considers appraising world resources as well, the quantity of source material that has to be sifted is immense. A bibliographic research staff can assemble the references pertinent to the subject, and where this is too voluminous to be efficiently examined by those responsible for planning a program, can abstract the information so that it can be more readily used. They can also be of material help in assembling information that must be studied in the prosecution of broader research problems such as the investigation of uranium-bearing black shales, (p. 13) radioactive spring and oil-well waters (p. 14), and the relation of uranium and thorium to particular stages of crystallization of some molten magmas. A thorough examination of this assembled literature will be a necessary preliminary to these and many other projects. Compilation of a map of the United States showing all reported resources of uranium- or thorium-bearing rocks or minerals is a job that also needs to be done.

The Union Mines Development Corporation developed a research staff for the purpose here outlined. This group has proven itself extremely useful, and has recently been transferred to the Geological Survey where it will continue with this type of work.

SUMMARY

The body of this report has summarized the results of investigations of the raw material resources of uranium and thorium by the Geological Survey and suggested specific topics or projects that should be included in a continuing program. Problems which have arisen during the course of current investigations are outlined. The proposals for future work are those that seem warranted on the basis of present information. Many of the proposed projects fall entirely within the scope of the Geological Survey's activities, others fall partly within the spheres of other groups whose information would aid the Survey's phase of the work, and still others fall wholly outside of the Survey's field of activity. Some of the last, especially detailed blocking out of reserves, either concurrently with or as a sequel to the Survey's investigations may lead to actual development and mining of domestic deposits of radioactive raw materials.

As the present report is an interim summary, an estimate of personnel needs and funds is not included. Specific proposals for projects and the funds necessary to carry out the Geological Survey's part of the program are now in preparation.

Arthur P. Butler, Chairman,
Special Committee on Report
to Atomic Energy Commission.